PHIL 290 Directed Studies 1 to 6 Term paper, 3 to 18 hours. Prerequisite(s): graduate standing; or consent of instructor. Directed study to meet special curricular needs. Students who submit a term paper receive a letter grade; other students receive a Satisfactory (S) No Credit (NC) grade. Course is repeatable.

PHIL 291 Individual Studies in Coordinated Areas 2 to 4 Prerequisite(s): graduate standing. A program of studies designed to advise and assist candidates who are preparing for the Comprehensive Examinations. Open to M.A. students only; does not count toward the unit requirement for the M.A. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHIL 292 Concurrent Analytical Studies in Philosophy 1 to 4 Prerequisite(s): consent of instructor. Each 292 course will be taken concurrently with some 100-series course, approved by the Graduate Advisor, but on an individual basis. It will be devoted to completion of a graduate paper based on research or criticism related to the 100-series course. Faculty guides and evaluations will be provided throughout the quarter. Graded Satisfactory (S) or No Credit (NC). May be repeated for credit.

PHIL 297 Directed Research 1 to 6 Prerequisite(s): graduate standing. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHIL 299 Research For Thesis Or Dissertation 1 to 12 Prerequisite(s): graduate standing. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

Professional Courses

PHIL 301 Directed Studies in the Teaching of Philosophy 1 Seminar, 1 hour. Prerequisite(s): graduate standing. A program of orientation, lectures, and workshops designed to enhance the Teaching Assistant's understanding of teaching methods in philosophy and to provide opportunities to work closely with experts in college teaching in order to improve the quality of instruction. Required of all new Teaching Assistants. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHIL 302 Teaching Practicum 1 to 4 Prerequisite(s): employment as Teaching Assistant or Associate. Supervised teaching in lower-division courses and LWSO 100. Required of all teaching assistants in philosophy. Does not count toward the unit requirement for the M.A. degree. Graded Satisfactory (S) or No Credit (NC). May be repeated for credit.

PHIL 400 Research and Professional Development Workshop 1 Workshop, 8 hours; extra reading, 8 hours. Prerequisite(s): graduate standing. A series of presentations and workshops focused on a variety of issues in research, professional development, and teaching. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 18 units.

Physical Sciences

College of Natural and Agricultural Sciences

The Physical Sciences major is not accepting new students at this time. For more information, contact the CNAS Undergraduate Academic Advising Center, 1223 Pierce Hall, or call (951) 827-7294.

Physics and Astronomy

Subject abbreviation: PHYS
College of Natural and Agricultural Sciences

Owen Long, Ph.D., Chair
Department Office, 3047 Physics
(951) 827-5331; physics.ucr.edu

Professors
Vivek Aji, Ph.D.
Barry Barish, Ph.D. *Distinguished Professor*
Kenneth N. Barish, Ph.D.
E. Gabriela Canalizo, Ph.D.
John A. Ellison, Ph.D.
Nathaniel Gabor, Ph.D.
J. William Gary, Ph.D.
Owen Long, Ph.D.
Allen P. Mills, Ph.D.
Bahram Mobasher, Ph.D *Distinguished Professor*
Umar Mohideen, Ph.D. *Distinguished Professor*
Leonid P. Pryadko, Ph.D.
Naveen Reddy, Ph.D.
Richard K. Seto, Ph.D.
Jing Shi, Ph.D.
Kirill Shtengel, Ph.D.
Harry W.K. Tom, Ph.D.
Shan-Wen Tsai, Ph.D.
Gillian Wilson, Ph.D.
Hai-Bo Yu, Ph.D.
Roya Zandi, Ph.D.

Professors Emeriti
Robert B. Clare, Ph.D.
Frederick W. Cummings, Ph.D.
Bipin R. Desai, Ph.D.
Sun-Yiu Fung, Ph.D.
Frederick Hamann, Ph.D.
Gail G. Hanson, Ph.D. *Distinguished Professor*
Peter E. Kaus, Ph.D.
Nai-Li H. Liu, Ph.D.
Ernest S. Ma, Ph.D.
Donald C. McCollum, Ph.D.
John C. Nickel, Ph.D.
Douglas E. MacLaughlin, Ph.D.
Raymond L. Orbach, Ph.D.
Eugen S. Simanek, Ph.D.
Chandra M. Varma, Ph.D.
Jose Wudka, Ph.D.
Jory A. Yarmoff, Ph.D.
Allen D. Zych, Ph.D.

Associate Professors
Michael G. Anderson, Ph.D.
Igor Barsukov, Ph.D.
George Becker, Ph.D.
Ward Beyermann, Ph.D.
Yanou Cui, Ph.D.
Yongtao Cui, Ph.D.
Anson D'Aloisio, Ph.D.
Joshua Lui, Ph.D.
Michael Mulligan, Ph.D.
Laura Sales, Ph.D.
Brian Siana, Ph.D.
Flip Tanedo, Ph.D.
Peng Wei, Ph.D.

Assistant Professors
Simeon Bird, Ph.D.
Boerge Hemmerling, Ph.D.
Thomas Kuhlman, Ph.D.
Miguel Arratia Munoz, Ph.D.
Jon Richardson, Ph.D.
Shawn Westerdale, Ph.D.

**

Major

The Department of Physics and Astronomy offers two undergraduate degrees: the B.A. and B.S. in Physics.

The **B.S. program** is designed for students with a strong interest in the sciences or engineering who wish to emphasize this aspect of their education and training. The B.S. degree provides a strong background for students who wish to continue on to graduate school.

The **B.A. program** follows the liberal arts tradition with a broader coverage of the humanities and social sciences. It is selected often by students who intend to obtain a teaching credential with a specialty in science or to pursue a career combining business management opportunities with a knowledge in science and technology.

The extensive course offerings and modern facilities within the Department of Physics and Astronomy, coupled with close, personal counseling by faculty advisors, provide students with a physics program that is characterized by its breadth and flexibility.

Career Opportunities

Graduates with a bachelor's degree in Physics generally begin their careers in government or industry. Professions include research and development, system modeling and analysis, and sales in a large variety of fields. A Physics degree provides one of the most flexible qualifications with direct applications to materials science, advanced electronics, lasers and microwave devices, computing and communications.

The federal government and national laboratories employ many physicists as do industries in medical and scientific instruments, computers, audio and telecommunications equipment, financial analysis and investments, material science, and engineering.

The bachelor's degree programs in the UCR Department of Physics and Astronomy are well suited for continued education in graduate school and for preparation in technical and professional careers. Colleges or universities, national laboratories, industry, and governmental agencies employ students with graduate training.

Transfer Students

Students transferring to the Physics major must complete courses comparable to the following one-year sequences before they transfer:

1. General physics (calculus-based) equivalent to PHYS 040A, PHYS 040B, PHYS 040C
2. First-year calculus, equivalent to MATH 007A or MATH 009A, MATH 007B or MATH 009B, MATH 009C

Students must have a minimum grade point average of 2.70 in transferable college courses. UCR has articulation agreements with most of the California community colleges. These agreements list specific community college courses that have been designated as comparable to UCR courses (see the statewide articulation Web site at **www.assist.org**). Transfer students will usually find it advantageous to complete most or all sequences before starting at UCR. All prospective transfers should try to complete the sequences they begin rather than divide a sequence between two campuses.

University Requirements

See Undergraduate Studies section.

College Requirements

See College of Natural and Agricultural Sciences, Colleges and Programs section.

Some of the following requirements for the major may also fulfill some of the college's breadth requirements. Consult with a department advisor for course planning.

Major Requirements

The major requirements consist of a core curriculum and additional requirements for various B.S. degrees. The core requirements for the B.A. and B.S. degrees in Physics are as follows:

1. **Lower-division requirements (70 units)**
   a) one of the following sequences: PHYS 041A, PHYS 041B, PHYS 041C, or PHYS 040A or PHYS 40HA, PHYS 040B or PHYS 40HB, PHYS 040C or PHYS 40HC, PHYS 040D, PHYS 040E. The first sequence is preferred for the B.S. in Physics.
   b) PHYS 039
   c) MATH 007A or MATH 009A or MATH 09HA, MATH 007B or MATH 009B or MATH 09HB, MATH 009C, MATH 010A, MATH 010B, MATH 046
   d) CHEM 001A, CHEM 001B, CHEM 001C, CHEM 01LA, CHEM 01LB, CHEM 01LC
   e) CS 010A or CS 009P. A higher-level CS course may satisfy this CS requirement with approval.
2. **Upper-division requirements (41 to 42 units)**
   a) PHYS 130A, PHYS 130B, PHYS 132, PHYS 135A, PHYS 135B, PHYS 156A, PHYS 156B
   b) PHYS 139L (5 units), PHYS 142L (4 units) or PHYS 142W (5 units). Note that PHYS142W satisfies the ENGL 001C requirement.
   c) 4 units of upper-division Physics electives. Upper-division math, science or engineering may be substituted with approval.

Physics: Standard Track (B.S. degree)

1. **Additional upper-division requirements (16 to 17 units)**
   a) PHYS 136
   b) One of the following: one additional quarter of PHYS 142L (4 units) or PHYS 142W (5 units); at least 4 units of Senior Thesis (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D); at least 4 units of Internship in Physics (PHYS 198I); participation in an approved summer research program, such as a NSF REU, and an additional 4 units of upper-division physics elective.
   c) 8 additional units of upper-division Physics electives. PHYS 156C is highly recommended for those planning to go to graduate school in physics.

Physics: Biophysics Track (B.S. degree)

1. **Additional lower-division requirements (25 units)**
   a) BIOL 005A, BIOL 005B, BIOL 005C, BIOL 05LA or BIOL 020.
   b) CHEM 008A, or CHEM 08HA, CHEM 008B or CHEM 08HB, CHEM 008C or CHEM 08HC, CHEM 08LA or CHEM 08HLA, CHEM 08LB or CHEM 08HLB, CHEM 08LC or CHEM 08HLC
2. **Additional upper-division requirements (8 units)**
   a) 8 additional upper-division units taken from BCH 110A, BCH 110B, BCH 110C or BIOL 107A (other upper-division CHEM/BIOL/BCH may be substituted upon approval)

Physics Education Track (B.S. degree)

1. **Additional lower-division requirements (6 units)**
   a) EDUC 003, EDUC 004
2. **Additional upper-division requirements (8 units)**
   a) Choose two courses from the following list: EDUC 105 (highly recommended), EDUC 147, EDUC 162, EDUC 132, EDUC 177, EDUC 179A

Physics: Applied Physics and Engineering Track (B.S degree)

1. **16 additional units of approved Engineering electives including a minimum of 8 units at the upper-division level.** A list of approved CS, EE, ME, CEE, CHE, and BIEN courses is available upon request from your physics faculty academic advisor or your advisor in the CNAS Advising Center. Example course plans can be found in the department web pages.

Physics: Astrophysics Track (B.S degree)

1. **Additional upper-division requirements (20 units)**
   a) PHYS 136, PHYS 111, PHYS 112, PHYS 166, PHYS 140L (PHYS 111, PHYS 112, or PHYS 166 can also satisfy the 4 units of upper-division core requirements in 2c. above.

Students continuing on to graduate school are encouraged to take additional upper-division courses in Mathematics, such as MATH 146A, MATH 146B, MATH 146C, MATH 165A, MATH 165B, and MATH 131.

Students may wish to earn a Minor in Mathematics which requires an additional 24 units of upper-division math.

To graduate, a minimum grade point average of 2.00 (C) is necessary overall and in the upper-division courses taken for the major (including upper-division courses listed under each track).

Bachelor of Arts

For the B.A. degree, additional units are required in Humanities, Social Sciences, and foreign language to meet the breadth requirements.

Minor

The minor in Physics consists of 26 upper-division units in Physics. A minimum of 16 units must be unique to the minor and may not be used to satisfy major requirements.

1. **First Tier (16 units)**
   a) PHYS 130A
   b) PHYS 132
   c) PHYS 135A
   d) One Upper Division Physics elective from PHYS 111, PHYS 150A, PHYS 151, PHYS 164, PHYS 165, PHYS 166, PHYS 177
2. **Second Tier: at least 10 units from any upper-division Physics courses not chosen in the First Tier.** The combined units from the First and Second Tiers should add to at least 26.
3. **No more than 4 units of 190-199 courses may be used to fulfill the upper-division units for the minor.**

See Minors under the College of Natural and Agricultural Sciences in the Colleges and Programs section of this catalog for additional information on minors.

Community College Transfers

The department provides special advisory services to aid community college transfer students in formulating their program and in remedying any deficiencies in required course work. Transfer students who have followed the prescribed program at the community college should be able to continue with the sample program at the junior level.

Graduate Program in Physics

The Department of Physics and Astronomy offers the M.S. and Ph.D. degrees in Physics.

Ongoing research in the Department of Physics and Astronomy includes astrophysics and space physics, condensed matter physics, particle physics, heavy ion physics, surface science, laser physics, and environmental physics. Large-scale experiments are carried out at the major U.S. and European accelerator laboratories or observatories.

Admission All applicants must submit scores from the GRE General and Physics subject tests. Questions about requirements for admission should be directed to the graduate advisor at (951) 827-5332.

Master's Degree

A student is recommended for the degree of M.A. or M.S. in Physics upon completion of the following requirements:

1. Satisfactory completion of a minimum of 36 quarter units of approved physics courses taken for a letter grade after admission to graduate study. Of these, at least 24 quarter units must be in the 200 series. Each course must be passed with a grade of "B-" or better. Each student must maintain an average for all courses of "B" or better.
2. Either of the following two plans:

Plan I (Thesis)
Satisfactory completion of a thesis in a field of physics to be chosen in consultation with a faculty supervisor. This thesis is approved by a committee designated by the department.

Plan II (Comprehensive Examination)
Satisfactory performance on the comprehensive examination.

Under either plan all requirements for the master's degree must be completed not later than the end of the sixth quarter.

Normative Time to Degree Six quarters

Doctoral Degree

The Department of Physics and Astronomy offers the Ph.D. degree in Physics.

It is recommended that students in the Ph.D. program become associated with a research advisor by the end of Spring Quarter of their first year.

A student is recommended for advancement to candidacy for the Ph.D. degree in Physics upon completion of requirements (1), (2), and (3) below. The student is recommended for the Ph.D. degree upon completion of requirements (4) and (5) below.

1. **Course Work**
   Each course must be passed with a grade of "B-" or better. Each student must maintain an average of "B" or better for all courses.

A. **Core courses for students pursuing a program in Physics (other than the Astrophysics Track):**

PHYS 205 (Classical Mechanics)

PHYS 210A, PHYS 210B, PHYS 210C (Electromagnetic Theory)

PHYS 212A, PHYS 212B (Thermodynamics and Statistical Mechanics)

PHYS 221A, PHYS 221B, PHYS 221C (Quantum Mechanics)

PHYS 296 (Summer Research in Physics and Astronomy)

PHYS 401 (Professional Development in Physics and Astronomy)

B. **Core courses for students pursuing a program in Physics on the Astrophysics Track:**

PHYS 205 (Classical Mechanics)

PHYS 210A, PHYS 210B, PHYS 210C (Electromagnetic Theory)

PHYS 212A (Thermodynamics and Statistical Mechanics, Part A)

PHYS 214 (Techniques of Observational Astrophysics)

PHYS 215 (Dynamics and Evolution of Galaxies)

PHYS 218 (Fundamentals of Astrophysics)

PHYS 219 (Cosmology and Structure Formation)

PHYS 296 (Summer Research in Physics and Astronomy)

PHYS 401 (Professional Development in Physics and Astronomy)

In addition, students in both programs must complete at least three additional elective graduate level lecture courses, taken for a letter grade. These courses must be physics or astronomy-related and relevant to the student's dissertation research. The program for each student must be approved by the Graduate Advisor and the student's Research Advisor. Such a program may entail more than the minimum number of courses and may also involve a mixture of courses from different areas.

The elective courses include the following, but other courses may be approved by the Graduate Advisor in consultation with the Graduate Advisory Committee:

a) **Condensed Matter, Surface, Biophysics and Atomic, Molecular and Optical Physics**

PHYS 209A (Quantum Electronics)

PHYS 209B (Nonlinear Optics)

PHYS 209C (Advanced Topics in Quantum Optics)

PHYS 234 (Physics of Nanoscale Systems)

PHYS 235 (Spintronics and Nanoscale Magnetism)

PHYS 240A, PHYS 240B (Condensed Matter Physics)

PHYS 241A, PHYS 241B, PHYS 241C (Advanced Statistical Physics and Field Theory)

PHYS 242 (Physics at Surfaces and Interfaces)

PHYS 245 (Atomic and solid-state physics with positrons)

PHYS 246 (Biological physics)

PHYS 260 (Special topics in Condensed Matter Physics)

b) **Nuclear and Particle Physics**

PHYS 224 (Frontiers of Physics and Astrophysics)

PHYS 225A, PHYS 225B (Elementary Particles)

PHYS 230A, PHYS 230B, PHYS 230C (Advanced Quantum Mechanics and Quantum Theory of Fields)

PHYS 262 (Special topics in High Energy Physics)

c) **Astronomy, Astrophysics, Cosmology and Astroparticle Physics**

PHYS 203 (Statistical Astronomy)

PHYS 204 (Advanced Galaxy Formation and Cosmology)

PHYS 208 (General Relativity)

PHYS 211A (Radiative Processes in Astrophysics)

PHYS 211B (Astrophysical Fluid Dynamics)

PHYS 213 (Astrophysics of the Interstellar Medium)

PHYS 216 (Star Formation)

PHYS 217 (Stellar Structure and Evolution)

PHYS 226 (Cosmology)

PHYS 227 (Particle Astrophysics)

PHYS 229 (Theory of dark matter halos and galaxies)

PHYS 261 (Special topics in Astrophysics)

2. **Written Comprehensive Examinations**
   Students must have satisfactory performance on a comprehensive examination, to be taken at the end of the student's first year. In the event of a failure, a make-up exam is offered in the winter quarter of the second year. The comprehensive examination for students pursuing the physics program consists of an exam that covers Mechanics, Statistical and Thermal Physics, Quantum Mechanics, and Electromagnetism. The comprehensive examination for students pursuing the astronomy specialization consists of an exam that covers Mechanics, Statistical and Thermal Physics, Electromagnetism, and Fundamental Astrophysics.

3. **Oral Qualifying Examination in General Area of Proposed Research**
   Satisfactory performance on an oral examination in the general area of the student's proposed research. This examination is conducted by a doctoral committee, charged with general supervision of the student's research. It is normally taken during the academic year following that in which the comprehensive examination requirement has been successfully completed. A student who fails this examination on the first attempt may, at the discretion of the committee, be permitted to take it a second time.
4. **Dissertation Examination**
   Students must complete a dissertation containing a review of existing knowledge relevant to the area of the candidate's research, and the results of the candidate's original research. This research must be of sufficiently high quality to constitute a contribution to knowledge in the subject area.
5. **Final Oral Examination**
   A final oral defense may be required.

Normative Time to Degree
18 quarters

Graduate Program in Astronomy

The Department of Physics and Astronomy offers the M.S. and Ph.D. degrees in Astronomy.

Ongoing research in the Department of Physics and Astronomy includes observational, theoretical, and computational astrophysics and cosmology. Observational programs are carried out at UC Observatories facilities, including Lick Observatory and the W. M. Keck Observatory, as well as with other national and international ground- and space-based facilities.

Admission
Students entering the program should have completed a Bachelor's (B.S. or B.A.) or Master's degree (M.S.) in Physics, Astrophysics, Astronomy, or a closely related field from an accredited 4-year college or university. This degree must represent the completion of a program that meets the standards established by the Graduate Division at the University of California, Riverside.

International applicants are required to take the TOEFL examination as part of the pre-qualification process for admission and financial support. The scores should be submitted directly from ETS and should have a test date no older than two years from the intended date of enrollment at UCR.

Doctoral Degree

The Department of Physics and Astronomy offers the Ph.D. degree in Astronomy.

A student is recommended for advancement to candidacy for the Ph.D. degree in Astronomy upon completion of requirements (1), (2), and (3) below. The student is recommended for the Ph.D. degree upon completion of requirements (4) and (5) below.

1. **Course Work**
   Each course must be passed with a grade of "B-" or better. Each student must maintain an average of "B" or better for all courses.

   Core Courses

   PHYS 206 (Computational Astrophysics)
   PHYS 211A (Radiative Processes in Astrophysics)
   PHYS 213 (Astrophysics of the Interstellar Medium)
   PHYS 214 (Techniques of Observational Astrophysics)
   PHYS 215 (Dynamics & Evolution of Galaxies)
   PHYS 217 (Stellar Structure & Evolution)
   PHYS 219 (Cosmology & Galaxy Formation)

First-year students will also take two quarters of PHYS 297 (Directed Research), starting in the Winter quarter. The advisor for this research will be chosen by the start of the Winter quarter.

In addition, students must complete two elective graduate-level courses, taken for a letter grade. These courses must be physics or astronomy-related and relevant to the student's dissertation research. The program for each student must be approved by the Graduate Advisor and the student's Research Advisor. Such a program may entail more than the minimum number of courses and may also involve a mixture of courses from different areas.

The elective courses include the following, but other courses may be approved by the Astronomy Graduate Advisor in consultation with the Astronomy Graduate Advisory Committee:

PHYS 203 (Statistical Astronomy)
PHYS 204 (Advanced Galaxy Formation and Cosmology)
PHYS 208 (General Relativity)
PHYS 211B (Astrophysical Fluid Dynamics)
PHYS 216 (Star Formation)
PHYS 218 (Fundamentals of Astrophysics)
PHYS 226 (Cosmology, Advanced Topics)
PHYS 227 (Particle Astrophysics)
PHYS 229 (Theory of Dark Matter Halos and Galaxies)
PHYS 247 (Introduction to Applied Data Science)
PHYS 261 (Special Topics in Astrophysics)

2. **Comprehensive Examination**
   Students must have satisfactory performance on a comprehensive examination, to be taken at the end of the student's first year. In the event of a failure, a make-up exam is offered by the end of the Fall quarter of the second year. The comprehensive examination for students pursuing the Astronomy program consists of (i) a written exam covering the core courses, and (ii) an oral report on the research undertaken during the two graded research classes taken in the first year.
3. **Oral Qualifying Examination in General Area of Proposed Research**
   Students must have satisfactory performance on an oral examination in the general area of the student's proposed research. This examination is conducted by a doctoral committee, charged with general supervision of the student's research. The exam must be taken before the end of the student's third year in the program. A student who fails this examination on the first attempt may, at the discretion of the committee, be permitted to take it a second time.
4. **Dissertation**
   Doctoral candidates must complete a satisfactory written dissertation that presents a review of existing knowledge relevant to the candidate's original research, an outline of specific problems addressed by the candidate's work, and a detailed description of the strategies, analysis techniques and results of the candidate's original research. The dissertation will be reviewed by a dissertation committee, charged with general supervision of the student's research.
5. **Final Oral Examination**
   Doctoral candidates must perform satisfactorily in a final oral defense of their dissertation before the candidate's dissertation committee. The oral defense will consist of a public presentation followed by a closed-door examination period with the committee.

   A student who fails (5) on the first attempt may, at the discretion of the committee, be permitted to take it a second time.

Professional Development
Students must complete PHYS 401 (Professional Development in Physics and Astronomy)

Normative Time to Degree
18 quarters

Master's Degree

A student is recommended for the degree of M.S. in Astronomy upon completion of the following requirements:

1. Satisfactory completion of the Core courses for the Doctoral Degree in Astronomy, including two quarters of PHYS 297 (Directed Research). Each course must be passed with a grade of "B-" or better. Each student must maintain an average for all courses of "B" or better.
2. Either of the following two plans:

   Plan I (Thesis)
   Satisfactory completion of a thesis in a field of astronomy to be chosen in consultation with a faculty supervisor. This thesis is approved by a committee designated by the department.

   Plan II (Comprehensive Examination)
   Satisfactory performance on the comprehensive examination.

Professional Development
Students must complete PHYS 401 (Professional Development in Physics and Astronomy)

Normative Time to Degree
6 quarters

Lower-Division Courses

Only one of the following sequences, PHYS 002A, PHYS 002B, PHYS 002C, or PHYS 040A, PHYS 040B, PHYS 040C may be taken for credit.

PHYS 002A General Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): concurrent enrollment in PHYS 02LA; MATH 007A with a grade of C- or better or MATH 009A with a grade of C- or better or MATH 09HA with a grade of C- or better. Covers topics in classical mechanics including Newton's laws of motion in one and two dimensions; work, energy, and conservation of energy; momentum and collisions; rotational motion; and orbital motion. For biological sciences students. Credit is awarded for one of the following PHYS 002A, PHYS 02HA, PHYS 040A, or PHYS 040HA.

PHYS 002B General Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 007B or MATH 009B or MATH 09HB (may be taken concurrently); PHYS 002A or PHYS 02HA with a grade of "C-" or better; concurrent enrollment in PHYS 02LB or a grade of "C-" or better in PHYS 02LB is required. Covers topics in mechanics, thermodynamics, and electromagnetism. Includes fluid mechanics; temperature and heat; the laws of thermodynamics; kinetic theory of gases; electric fields and potentials; current and DC circuits; capacitance and inductance; magnetism; and Faraday's law. For biological sciences students. Credit is not awarded for PHYS 002B if it has already been awarded for PHYS 02HB; PHYS 040B or PHYS 040HB and PHYS 040C or PHYS 040HC; or PHYS 041B.

PHYS 002C General Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 002B or PHYS 02HB with a grade of "C-" or better; concurrent enrollment in PHYS 02LC or a grade of "C-" or better in PHYS 02LC. Covers topics in waves and modern physics. Includes harmonic oscillations; mechanical and electromagnetic waves; geometrical optics; reflection, refraction, interference, diffraction, and polarization; and quantum, atomic, and nuclear physics. For biological sciences students. Credit is not awarded for PHYS 002C; if it has already been awarded for PHYS 02HC; or PHYS 041C.

PHYS 02HA Honors General Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 007A or MATH 009A or MATH 09HA with a grade of B- or better; concurrent enrollment in PHYS 2HLA or a grade of B- or better in PHYS 02HLA. Honors course corresponding to PHYS 002A. Covers topics in classical mechanics including Newton's laws of motion in one and two dimensions; work, energy, and conservation of energy; momentum and collisions; rotational motion; and orbital motion. For biological sciences students. Satisfactory (S) or No Credit (NC) grading is not available. Credit is not awarded for PHYS 02HA if it has already been awarded for PHYS 002A or PHYS 040A or PHYS 040HA or PHYS 041A.

PHYS 02HB Honors General Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 002A or PHYS 02HA; MATH 007B or MATH 009B or MATH 09HB with a grade of B- or better; concurrent enrollment in PHYS 02HLB or a grade of B- or better in PHYS 02HLB. Honors course corresponding to PHYS 002B. Covers topics in mechanics, thermodynamics, and electromagnetism. Includes fluid mechanics; temperature and heat; the laws of thermodynamics; kinetic theory of gases; electric fields and potentials; current and DC circuits; capacitance and inductance; magnetism; and Faraday's law. For biological sciences students. Satisfactory (S) or No Credit (NC) grading is not available. Credit is not awarded for PHYS 02HB if it is already awarded for PHYS 002B; or both PHYS 040B or PHYS 040HB and PHYS 040C or PHYS 040HC; or PHYS 041B.

PHYS 02HC Honors General Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 002B or PHYS 02HB with a grade of "B-" or better; concurrent enrollment in PHYS 02HLC or a grade of "B-" or better in PHYS 02HLC. Honors course corresponding to PHYS 002C. Covers topics in waves and modern physics. Includes harmonic oscillations; mechanical and electromagnetic waves; geometrical optics; reflection, refraction, interference, diffraction, and polarization; and quantum, atomic, and nuclear physics. For biological sciences students. Satisfactory (S) or No Credit (NC) grading is not available. Credit is not awarded for PHYS 002C if it has already been awarded for PHYS 02HC; or PHYS 041C.

PHYS 02HLA Honors General Physics Laboratory 1 Laboratory, 3 hours. Prerequisite(s): concurrent enrollment in PHYS 02HA or a grade of "B-" or better in PHYS 02HA. Honors course corresponding to PHYS 02LA. Illustrates the experimental foundations of physics presented in PHYS 002A. Covers the basic principles of classical mechanics. Satisfactory (S) or No Credit (NC) grading is not available. Credit is awarded for only one of PHYS 02LA or PHYS 02HLA.

PHYS 02HLB Honors General Physics Laboratory 1 Laboratory, 3 hours. Prerequisite(s): PHYS 02HA or PHYS 002A with a grade of "B-" or better; PHYS 02HLA or PHYS 02LA with a grade of "B-" or better; concurrent enrollment in PHYS 02HB or a grade of "B-" or better in PHYS 02HB. Honors course corresponding to PHYS 02LB. Illustrates the experimental foundations of physics presented in PHYS 02HB. Covers the basic principles of fluid and rotational mechanics, temperature, heat, and electromagnetism. Satisfactory (S) or No Credit (NC) grading is not available. Credit is awarded for only one of PHYS 02LB or PHYS 02HLB.

PHYS 02HLC Honors General Physics Laboratory 1 Laboratory, 3 hours. Prerequisite(s): PHYS 02HB or PHYS 002B with a grade of "B-" or better; PHYS 02HLB or PHYS 02LB with a grade of "B-" or better; concurrent enrollment in PHYS 02HC or a grade of "B-" or better in PHYS 02HC. Honors course corresponding to PHYS 02LC. Illustrates the experimental foundations of physics presented in PHYS 002C. Covers the basic principles of oscillations, waves, optics, and radioactivity. Satisfactory (S) or No Credit (NC) grading is not available. Credit is awarded for only one of PHYS 02LC or PHYS 02HLC.

PHYS 02LA General Physics Laboratory 1 Laboratory, 3 hours. Prerequisite(s): concurrent enrollment or a grade of "C-" or better in PHYS 002A or PHYS 02HA. Illustrates the experimental foundations of physics presented in PHYS 002A. Covers the basic principles of classical mechanics. Credit awarded for only PHYS 02LA or PHYS 02HLA.

PHYS 02LB General Physics Laboratory 1 Laboratory, 3 hours. Prerequisite(s):PHYS 002A and PHYS 02LA or PHYS 02HA and PHYS 02HLA with grades of "C-" or better; concurrent enrollment or a grade of "C-" or better in PHYS 002B or PHYS 02HB. Illustrates the experimental foundations of physics presented in PHYS 002B. Covers the basic principles of fluid and rotational mechanics, temperature, heat, and electromagnetism. Credit is awarded for only one of PHYS 02LB or PHYS 02HLB.

PHYS 02LC General Physics Laboratory 1 Laboratory, 3 hours. Prerequisite(s): PHYS 002B and PHYS 02LB or PHYS 02HB and PHYS 2HLB with a grade of "C-" or better; concurrent enrollment or a grade of "C-" or better in PHYS 002C or PHYS 02HC Illustrates the experimental foundations of physics presented in PHYS 002C. Covers the basic principles of oscillations, waves, optics, and radioactivity. Credit is awarded for only one of PHYS 02LC or PHYS 02HLC.

PHYS 005 History of the Universe 4
Lecture, 3 hours; discussion, 1 hour. An introduction to "The Big Bang" model and its observational tests. Topics include dark energy, dark matter, rapid growth of universe at early times, leftover radiation from "The Big Bang", galaxy formation, bending of light by gravity, black holes, extraterrestrial life, and the likely fate of the universe.

PHYS 006 The Violent Universe 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. An introduction to violent phenomena that power the universe, specifically phenomena that illustrate basic astrophysical principles. Topics include impacts in our planetary system: explosions of stars, bursts of star formation, galaxy collisions, black holes, quasars, cosmic jets, and the "Big Bang."

PHYS 007 Space Time, Relativity, and Cosmology 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. A non-mathematical presentation on gravity, understanding of the universe, and how present theories originated. Topics include the ancient Greeks, Galileo, Newton, the speed of light, Einstein's special and general relativity, the lifetimes of stars, supernovas, gravity waves, the Big Bang, cosmic inflation, and the multiverse.

PHYS 008 Color and Sound: Dimensions in Communication 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Discusses the interplay between visual and aural sensory experiences and the physical principles of light and sound. Topics include visual perception and pattern recognition; the color spectrum; optical instruments; anatomy of the camera and the eye; lasers and holography; vibrations and sound waves; acoustics; reverberation; and sound production in speech, music, and high-fidelity audio devices. Involves demonstrations and illustrations.

PHYS 010 How Things Work 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Surveys the physical basis of modern technology emphasizing electronics and electrical devices. Topics include electro- and magneto-statics and dynamics (xerographic copiers, magnetic levitation, electrical power distribution); communication (radio, TV, computers, tape recorders, CD players); and imaging (cameras, DVD players, x rays, magnetic resonance imaging).

PHYS 016 Principles of Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 005A is recommended. Topics include classical laws of motion, force, energy, electricity and magnetism, properties of matter, atomic structure, waves, sound, light, heat, the Earth, and the solar system and universe. Includes demonstrations and visual illustrations. Not open to students with credit or concurrent enrollment in PHYS 002A or PHYS 02HA or PHYS 002B or PHYS 02HB or PHYS 002C or PHYS 02HC or PHYS 040A or PHYS 040HA or PHYS 040B or PHYS 040HB or PHYS 040C or PHYS 040HC or PHYS 040D or PHYS 040E.

PHYS 017 Linear Algebra For Physics 4
Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B with a grade of C- or better, MATH 046 with a grade of C- or better. This course covers the essential mathematics for quantum mechanics at the upper-division level. It applies linear algebra to finite and infinite dimensional vector spaces. Topics include: matrices, linear equations, bases, eigenvectors and eigenvalues, functions as infinite-dimensional vectors, differential operators as matrices, Fourier transforms, and eigenfunctions of common differential operators.

PHYS 018 Energy and the Environment 4
Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Covers the physics of energy (thermal, kinetic, potential, chemical, nuclear), its storage and use, primary sources of energy (fossil fuel, nuclear, wind, solar) and their relative effects on the environment. Particular emphasis on determining individual carbon footprints, physical models of global climate change and identifying pathways toward a sustainable infrastructure.

PHYS 020 Exploring the Universe: An Adventure in Astronomy 4 Lecture, 3 hours; workshop, 3 hours. Prerequisite(s): none. An astronomy course for non-science students. The excitement of an evolving and sometimes violent universe of stars and galaxies is explored in a descriptive manner. Here, the union of modern and ancient observations with astrophysical laws will provide a sophisticated but by no means complete picture of the universe. Special topics such as Astrology and Extraterrestrial Life will be discussed.

PHYS 024 DNA in Your Life: the Physical Basis For Structure, Function, and Control 4
Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. An introduction to various medical, biological, and commercial aspects of physical DNA science.

PHYS 037 The Origins 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none
Explores the most fundamental questions in cosmology, physics, and chemical sciences through their origins. Topics include the origin of the Universe, origin of matter, first generation of stars and galaxies, origin of chemical elements, chemistry of life, and astrobiology.

PHYS 039 Adventures in Physics 3 Lecture, 3 hours. Prerequisite(s): restricted to major(s) Physics; or consent of instructor. Covers professional development including career options for physics majors and provides pathways to undergraduate research opportunities. Includes aspects of physics relevant to current social and political issues.

PHYS 040A General Physics 5 Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 007A or MATH 009A or MATH 09HA with a grade of "C-" or better; MATH 007B or MATH 009B or MATH 09HB with a grade of "C-" or better (MATH 009B or MATH 09HB may be taken concurrently). Designed for engineering and physical sciences students. Covers topics in classical mechanics including Newton's laws of motion; friction; circular motion; work, energy, and conservation of energy; dynamics of particle systems; collisions; rigid-body motion; torque; and angular momentum. Laboratories provide exercises illustrating experimental foundations of physical principles and selected applications. Credit is not awarded for PHYS 040A if it has already been awarded for PHYS 002A, PHYS 02HA, PHYS 040HA, or PHYS 041A.

PHYS 040B General Physics 5 Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 009C or MATH 09HC (may be taken concurrently); PHYS 040A or PHYS 040HA with a grade of "C-" or better. Designed for engineering and physical sciences students. Covers topics in mechanics and thermodynamics including elasticity; oscillations; gravitation; fluids; mechanical waves and sound; temperature, heat, and the laws of thermodynamics; and the kinetic theory of gases. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Credit is awarded for only one of PHYS 040B or PHYS 040HB.

PHYS 040C General Physics 5 Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 009C or MATH 09HC; PHYS 040B or PHYS 040HB with a grade of "C-" or better. Designed for engineering and physical sciences students. Covers topics in electricity and magnetism including electric fields and potential; Gauss' law; capacitance; magnetic fields; Ampere's law; Faraday's law and induction; electromagnetic oscillations; dc and ac current; and circuits. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Credit is awarded for only one of PHYS 040C, PHYS 040HC, PHYS 002B, PHYS 02HB, or PHYS 041B.

PHYS 040D General Physics 5 Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): PHYS 040C or PHYS 040HC with a grade of "C-" or better or consent of instructor. For engineering and physical sciences students. Topics in electromagnetic waves including Maxwell's equations; geometrical optics; optical instruments, cavities, and waveguides; interference, diffraction, and polarization; and special theory of relativity. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Credit is not awarded for PHYS 040D if it has already been awarded for PHYS 002C or PHYS 041C.

PHYS 040E General Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 046 (may be taken concurrently); PHYS 040D with a grade of "C-" or better. For engineering and physical sciences students. Covers topics in modern physics including the quantum theory of light and particles; quantum mechanics in one and three dimensions; tunneling phenomena; the hydrogen atom; statistical physics; lasers; molecular structure; and solid state, nuclear, and particle physics. Credit is not awarded for PHYS 040E if it has already been awarded for PHYS 002C or PHYS 02HC or PHYS 041C.

PHYS 040HA Honors General Physics 5 Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 007A with a grade of C- or better or MATH 009A with a grade of C- or better or MATH 009HA with a grade of C- or better; MATH 007B with a grade of C- or better or MATH 009B with a grade of C- or better, may be taken concurrently or MATH 09HB with a grade of C- or better, may be taken concurrently; admission to University Honors. Honors course corresponding to PHYS 040. Designed for engineering/physical sciences students. Topics in classical mechanics: Newton's laws of motion; friction; circular motion; work, energy, conservation of energy; dynamics of particle systems; collisions; rigid-body motion; torque; angular momentum. Laboratories provide exercises illustrating experimental foundations of physical principles and selected applications. Satisfactory(S) or No Credit(N/C) is not available. Credit is awarded for one of the following: PHYS 040HA, PHYS 002A, PHYS 02HA, PHYS 040A, or PHYS 041A;

PHYS 040HB Honors General Physics 5 Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 009C or MATH 09HC (may be taken concurrently); PHYS 040HA with a grade of B- or better or PHYS 040A with a grade of B- or better. Honors course corresponding to PHYS 040B. Designed for engineering and physical sciences students. Covers topics in mechanics and thermodynamics including elasticity; oscillations; gravitation; fluids; mechanical waves and sound; temperature, heat, and the laws of thermodynamics; and the kinetic theory of gases. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Satisfactory (S) or No Credit (NC) grading is not available. Credit is awarded for only one of PHYS 040B or PHYS 040HB.

PHYS 040HC Honors General Physics 5 Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 009C or MATH 09HC; PHYS 040B or PHYS 040HB with a grade of "C-" or better. Honors courses corresponding to PHYS 040C. Designed for engineering and physical sciences students. Covers topics in electricity and magnetism including electric fields and potential; Gauss' law; capacitance; magnetic fields; Ampere's law; Faraday's law and induction; electromagnetic oscillations; dc and ac current; and circuits. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Satisfactory (S) or No Credit (NC) grading is not available. Credit is awarded for only one of PHYS 040C, PHYS 040HC, PHYS 002B, PHYS 02HB, or PHYS 041B.

PHYS 041A Introductory Physics For Physics Majors 8 Lecture, 4 hours; discussion, 2 hours; laboratory, 6 hours. Prerequisite(s): MATH 007A or MATH 009A or MATH 09HA with a grade of "C-" or better (MATH 007A or MATH 009A or MATH 09HA may be taken concurrently). Covers topics in classical mechanics, including Newton's laws of motion in one and two dimensions; work, energy, and conservation of energy; momentum and collisions; rotational motion; and orbital motion. Credit is not awarded for PHYS 041A if it has already been awarded for PHYS 040A, PHYS 040HA, PHYS 002A, or PHYS 02HA

PHYS 041B Introductory Physics For Physics Majors 8 Lecture, 4 hours; discussion, 2 hours; laboratory, 6 hours. Prerequisite(s): MATH 007B or MATH 009B or MATH 09HB with a grade of "C-" or better (MATH 007B or MATH 009B or MATH 09HB may be taken concurrently); PHYS 002A with a grade of "B-" or better or PHYS 040A with a grade of "C-" or better or PHYS 041A with a grade of "C-" or better or consent of instructor. Covers relativity oscillations, mechanical waves, fluids, electrostatics, magnetism, and circuits. Credit is not awarded for PHYS 041B if it has already been awarded for PHYS 040C.

PHYS 041C Introductory Physics For Physics Majors 8 Lecture, 4 hours; discussion, 2 hours; laboratory, 6 hours. Prerequisite(s): MATH 009C with a grade of "C-" or better or MATH 09HC with a grade of "C-" or better (MATH 009C or MATH 09HC may be taken concurrently); PHYS 002B or PHYS 02HB with a grade of "B-" or better or PHYS 040C or PHYS 040HC with a grade of "C-" or better or PHYS 041B with a grade of "C-" or better or consent of instructor. Covers electromagnetism, geometric and wave optics, and modern physics. Credit is not awarded for PHYS 041C if it has already been awarded for both PHYS 040D and PHYS 040E.

PHYS 050 Introduction to Applied Data Science: A Multi-Disciplinary Approach 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Introduces students from different disciplines (physical, biological, engineering, finance, economy, humanities) to data science techniques and applications. Provides background knowledge in data science and prepares for a career in this field. Provides basic knowledge to continue on to more advanced topics in data science and apply it to practical problems.

PHYS 097 Lower-Division Research 1 to 4 Individual Study, 3 to 12 hours. Prerequisite(s): consent of instructor. Special research projects in physics performed under the supervision of a member of the staff. This course may not be used to satisfy the undergraduate unit requirements in the major. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 8 units.

Upper-Division Courses

PHYS 111 Astrophysics and Stellar Astronomy 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 046, or equivalents; one of the following: PHYS 040D with a grade of C- or better, PHYS 041C with a grade of C- or better, PHYS 002C with a grade of B- or better. Covers stellar interiors, radiations, and evolution; the origin of the elements; particle and electromagnetic radiation; pulsars, quasars, and other unusual objects; and galactic structure and cosmology.

PHYS 112 Galaxies and Extragalactic Astronomy 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 111 with a grade of C- or better. Topics include the structure of the Milky Way, the observed properties of galaxies, active galactic nuclei and supermassive black holes, the intergalactic medium, the theory of galaxy formation and evolution, galaxy clusters, and the large scale structure of our universe.

PHYS 117 Advanced Mathematical Methods of Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B with a grade of C- or better, MATH 046 with a grade of C- or better. This course covers advanced mathematical for upper division and graduate physics courses. Topics include dimensional analysis, infinite dimensional vector spaces, integral transforms, complex analysis, and the use of Green's functions to solve inhomogeneous differential equations. This course is strongly recommended for students with a focus on theoretical physics.

PHYS 130A Classical Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009C, MATH 010A (may be taken concurrently); one of the following: PHYS 002A or PHYS 02HA with a grade of B- or better, PHYS 040A or PHYS 040HA with a grade of C- or better, PHYS 041A with a grade of C- or better. Explores vector calculus, single-particle motion, oscillations, Lagrangian and Hamiltonian dynamics, central-forces motion, and celestial mechanics.

PHYS 130B Classical Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A, MATH 010B (may be taken concurrently), PHYS 130A. Topics include dynamics of a system of particles, motion in non-inertial reference systems, dynamics of rigid bodies, coupled oscillations, and special theory of relativity.

PHYS 132 Thermal Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B; MATH 046 (may be taken concurrently); PHYS 130B. Covers thermodynamics and an introduction to statistical mechanics. Topics include states of a model system; entropy and temperature; the Boltzmann distribution and Helmholtz free energy; thermal radiation and the Planck distribution; chemical potential; the ideal gas; Fermi and Bose gasses; and heat and work.

PHYS 133 Advanced Statistical Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 132 and PHYS 156B. Covers advanced topics in statistical mechanics, ensembles, and classical and quantum statistical mechanics. Explores the connection between statistical mechanics and thermodynamics.

PHYS 135A Electromagnetism 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B; MATH 046; one of the following: PHYS 002B or PHYS 02HB with B- or better, PHYS 040C or PHYS 040HC with a C- or better, PHYS 041B with a C- or better. Topics include vector calculus; Coulomb's law and the electric field; Gauss' law; scalar potential; conductors in electrostatic fields; electrostatic energy; electric multipoles; boundary conditions; electrostatics in the presence of matter; and special methods in electrostatics.

PHYS 135B Electromagnetism 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 135A. Topics include electric currents and circuits, Ampere's law, the magnetic field, the integral form of Ampere's law, the vector potential, Faraday's law of induction, magnetic energy, magnetic multipoles, magnetism in the presence of matter, Maxwell's equations, and plane waves.

PHYS 136 Electromagnetic Waves 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 135B. Covers Maxwell's equations; propagation of electromagnetic waves in wave guides, coaxial lines, and optical fibers; reflection, refraction, and diffraction of waves; dispersion of waves in gases and plasmas; interference and coherence and their role in holography; electromagnetic radiation from charged particles, antennas, masers, and lasers; and relativistic electrodynamics.

PHYS 139L Electronics For Scientists 5 Lecture, 3 hours; laboratory, 6 hours. Prerequisite(s): One of the following: PHYS 002B or PHYS 02HB with B- or better, PHYS 040C or PHYS 040HC with a C- or better, PHYS 041B with a C- or better, or consent of instructor. Introduces basic analog and digital circuit designs that emphasize practical applications. Includes properties of diodes and transistors; operational amplifiers for use as amplifiers, oscillators, and function generators; properties and use of logic gates, counters, and timers; data storage and synchronization; multiplexer and decoder applications; microprocessor functions; and computer interfacing.

PHYS 140L Techniques of Observational Astronomy 4 Lecture, 2 hours; laboratory, 6 hours. Prerequisite(s): PHYS 002C with a grade of B- or better or PHYS 02HC with a grade of B- or better or PHYS 040E with a grade of C- or better or PHYS 041C with a grade of C or better; restricted to major(s) Physics; or consent of instructor. Covers modern techniques of observational astronomy including digital optical imaging, photometry, spectroscopy, radio observations, error propagation and statistical inference. Lab practicum includes calibrating digital images and spectra, computer programming for data analysis, quantifying uncertainties in astronomical measurements, and written communication of scientific results.

PHYS 142L Advanced Physics Laboratory 4 Laboratory, 12 hours. Prerequisite(s): PHYS 002C with a grade of B- or better or PHYS 02HC with a grade of B- or better or PHYS 040E with a grade of C- or better or PHYS 41C with a grade of C- or better; restricted to class level standing of senior; restricted to major(s) Physics; or consent of instructor. A capstone experience consisting of experiments chosen from areas in contemporary physics. Course is repeatable to a maximum of 8 units. Credit is awarded to a maximum of 10 units for either or both PHYS 142L and/or PHYS 142W.

PHYS 142W Advanced Physics Laboratory 5 Laboratory, 11 hours; individual study, 6 hours; workshop, 0.8 hour. Prerequisite(s): ENGL 001B with a grade of C or better; PHYS 002C with a grade of B- or better or PHYS 02HC with a grade of B- or better or PHYS 040E with a grade of C- or better or PHYS 041C with a grade of C- or better; ENGL 007, may be taken concurrently; for concurrent enrollment in ENGL 007, review the course titles or topics in the current online Schedule of Classes to find the corresponding ENGL 007 writing workshop; restricted to class level standing of senior; or consent of instructor. A capstone experience consisting of experiments chosen from areas in contemporary physics. Includes writing instruction with an emphasis on technical communication. Fulfills the third-quarter writing requirement for students who earn a grade of "C" or better for courses that the Academic Senate designates, and that the student's college permits, as alternatives to English 001C. Course is repeatable to a maximum of 10 units. Credit is awarded to a maximum of 10 units for either or both PHYS 142L or PHYS 142W.

PHYS 145A Biophysics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CHEM 001C or CHEM 01HC; MATH 010B; MATH 046; one of the following: PHYS 002C or PHYS 02HC with B- or better, PHYS 041C with a C- or better, PHYS 040E with a C- or better. Covers physical modeling of the structure of proteins; protein folding; structure of nucleic acids; electrostatic potential of DNA; dynamics of biomolecules; structure of a biological cell; osmotic pressures of cells; non-equilibrium thermodynamics; and biochemical reactions.

PHYS 145B Biophysics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 145A; BCH 100 or BCH 110B or BCH 110HB; or consent of instructor. Covers conformation of biopolymers, intermolecular forces, dynamics of biopolymers, Brownian motion, biopolymers as polyelectrolytes, electrolytic solutions, and the Debye-Huckel theory.

PHYS 145C Biophysics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 145B or consent of instructor. Examines stochastic thermodynamics; the Fluctuation Theorems and the Jarzynski relation; protein and RNA denaturation; tests of the Jarzynski relation; chemical forces and self-assembly; enzymes and molecular machines; survey of molecular devices found in cells; and kinetics of real enzymes and machines.

PHYS 150A Introduction to Condensed Matter Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): One of the following: PHYS 002B with B- or better, PHYS 040E with a C- or better, PHYS 041C with a C- or better; or consent of instructor. Covers properties of systems composed of many atoms arranged in a periodic lattice. Topics include crystal structure, symmetry, and diffraction; crystal cohesion; lattice dynamics; thermal properties; metallic properties and the Fermi surface; band theory of metals and semiconductors; and collective excitations.

PHYS 150B Introduction to Condensed Matter Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 150A. Covers properties of systems composed of many atoms arranged in a periodic lattice. Topics include superconductivity; magnetism; non-crystalline solids; defects in solids; surface and interface physics; and alloys.

PHYS 151 Topics in Modern Condensed Matter Research 4 Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): One of the following: PHYS 002B or BCH 110HB with a grade of "B-" or better, PHYS 040E with a C- or better, PHYS 041C with a grade of "C-" or better. Consent of instructor is required for students repeating the course. Introduces cutting-edge physics research being conducted in laboratories and institutes around the world. Focuses on a single research area (e.g., nanoscale physics, biological physics) that may change each quarter. Includes experimental methods and theoretical concepts. Course is repeatable as content changes to a maximum of 12 units.

PHYS 152A Exploring Many-Body Quantum Physics With Mathematica 2 Lecture, 2 hours. Prerequisite(s): MATH 046; one of the following: PHYS 002C with a B- or better, PHYS 040E with a C- or better, PHYS 041C with a C- or better; or consent of instructor. MATH 031 is recommended. An introduction to numerics and visualization using Mathematica. Topics include random numbers and stochastic processes; time-dependent and stationary equations in matrix form; single-particle tight-binding model; single-spin dynamics; pure and mixed states; spin echo; the direct product of matrices; many-body quantum mechanics; and quantum spin chains.

PHYS 152B Exploring Many-Body Quantum Physics With Mathematica 2 Lecture, 2 hours. Prerequisite(s): PHYS 152A or consent of instructor. Covers the symmetry of many-body wavefunction, including bosons and fermions; secondary quantization; harmonic oscillators; ladder operators, eigenvalues, and eigenfunctions; interacting many-body systems; mean field approximation; and density matrix of a subsystem and decoherence.

PHYS 156A Quantum Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 046, PHYS 130B; one of the following: PHYS 002C or PHYS 02HC with a grade of "B-" or better, PHYS 040E with a grade of "C-" or better, PHYS 041C with a grade of "C-" or better. Topics include wave-particle duality, the Schrodinger equation, superposition, the uncertainty principle, and one-dimensional harmonic oscillator.

PHYS 156B Quantum Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156A. Topics include the hydrogen atom, angular momentum and spin representations, many-electron systems, the Pauli exclusion principle, and perturbation theory.

PHYS 156C Quantum Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156B. Applications in quantum mechanics. Includes perturbation theory and other approximations, scattering, and an introduction to advanced topics such as relativistic quantum mechanics.

PHYS 163 Atomic Physics and Spectroscopy 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CHEM 113 or PHYS 156A with a C- or better, PHYS 135A with a C- or better, or consent of instructor. Covers the role of atomic physics and spectroscopy in the development of quantum mechanics; Bohrs old quantum theory; Heisenbergs matrix mechanics; Schrodingers wave mechanics; Dirac equation; the g-factor; Zeeman effect and the Darwin term; Spin-orbit coupling and Thomas precession; Dirac hydrogen atom; Fine structure; Hyperfine structure; Lamb shift.

PHYS 164 Introduction to Nuclear Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): One of the following: PHYS 002C or PHYS 02HC with a grade of "B-" or better, PHYS 040E with a grade of "C-" or better, PHYS 041C with a grade of "C-" or better. Addresses the basic nuclear properties, as well as the nuclear building blocks and structure. Explores radioactivity, nuclear interactions, the strong force, the confinement and chiral phase transitions, the quantum chromodynamics (QCD) vacuum, and matter at extreme temperatures and densities.

PHYS 165 Introduction to Particle Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156A. Explores the classification of particles in terms of the Standard Model. Includes methods and techniques for particle acceleration and detection; conservation laws and symmetries; the basic interactions of particles (electromagnetic, strong, weak); and electroweak unification.

PHYS 166 Cosmology 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156A. Discusses current topics in astrophysics and cosmology from the perspective of elementary particle physics. Topics include the development and structure of the early universe, dark matter and dark energy, cosmic radiation, and particle physics in the stars.

PHYS 168 Energy and the Environment 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B with a grade of C- or better, PHYS 040C with a grade of C- or better or PHYS 041C with a grade of C- or better; or consent of instructor. Explores physical insights into primary energy uses in society such as electricity, transportation, and heating. Explains how that energy is obtained and transformed (e.g., fossil fuels, nuclear, hydropower, heat engines). Also addresses renewable energy (photovoltaics, wind, batteries, fuel cells) in the context of climate change and sustainability.

PHYS 177 Computational Methods For Physical Sciences 4 Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): CS 009A or CS 010A or CS 010B; PHYS 002C with a grade of B- or better or PHYS 02HC with a grade of B or better or PHYS 040E with a grade of C- or better or PHYS 041C with a grade of C- or better; or consent of instructor. Covers computer applications for solving problems in physical sciences. Addresses symbolic manipulation languages such as Mathematica, mathematical operations, plotting, and symbolic and numerical techniques in calculus. Includes numerical methods such as histogramming, the Monte-Carlo method for modeling experiments, statistical analysis, curve fitting, and numerical algorithms.

PHYS 190 Special Studies 1 to 5 Individual Study, 3 to 15 hours. Prerequisite(s): consent of department chair Individual study to meet special curricular needs. May not be used to satisfy major requirements unless taken as a replacement for a course not being offered during the student's remaining tenure. Course is repeatable to a maximum of 9 units; a maximum of 5 units may be used to substitute for PHYS 142L.

PHYS 190L Special Studies at Los Alamos National Laboratory 1 to 8 Individual Study, 3 to 24 hours. Prerequisite(s): admission to the UCR/LANL Educational Internship Program; consent of advisor and department chair. Individual study to meet special curricular needs. Course is repeatable to a maximum to 16 units.

PHYS 195A Senior Thesis 1 to 4 Thesis, 3 to 12 hours; Prerequisite(s): senior standing; consent of instructor. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L.

PHYS 195B Senior Thesis 1 to 4 Thesis, 3 to 12 hours. Prerequisite(s): senior standing; consent of instructor; PHYS 195A. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L.

PHYS 195C Senior Thesis 1 to 4 Thesis, 3 to 12 hours. Prerequisite(s): senior standing; consent of instructor; PHYS 195B. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L

PHYS 195D Senior Thesis 1 to 4 Thesis, 3 to 12 hours. Prerequisite(s): senior standing; consent of instructor; PHYS 195C. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L.

PHYS 197 Research For Undergraduates 1 to 4 Individual Study, 3 to 12 hours. Prerequisite(s): upper-division standing and consent of instructor. Special research projects in physics performed under the supervision of a member of the staff. This course may not be used to satisfy the undergraduate unit requirement in the major. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 8 units.

PHYS 198I Individual Internship in Physics 1 to 12 Written Work, 1 to 12 hours; internship, 2 to 24 hours. Prerequisite(s): upper-division standing; consent of department chair. Provides experience as a practicing scientist in a government or industrial laboratory. Includes joint supervision by an off-campus sponsor and a Physics faculty member. Course is repeatable to a maximum of 12 units; a maximum of 4 units may be used to satisfy major requirements, and a maximum of 5 units may be used to substitute for PHYS 142L.

Graduate Courses

PHYS 202 Interdisciplinary Overview of Current Issues in Semiconductor Processing 3 Lecture, 3 hours. Prerequisite(s): graduate standing in Chemistry, Physics, Engineering, or a related subject or consent of instructor. An interdisciplinary overview of present-day semiconductor processing. Introduces topics such as properties of semiconductors, cleanroom environment, epitaxy, ion implantation, etching, lithography, device architecture, testing, and fault detection. May offer field trips. Cross-listed with CHEM 208, and MSE 245D.

PHYS 203 Statistical Astronomy 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 218. Introduces statistical methods needed to analyze astronomical data. Provides case examples of problems in observational astronomy and applies statistical techniques to solve them. Covers probability, correlation and association, hypothesis testing, data modelling, maximum likelihood technique, detection and surveys, sequential data, and surface distribution. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 204 Advanced Galaxy Formation and Cosmology 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 218; PHYS 219; graduate standing; or the consent of instructor. Covers topics on galaxy formation, star formation in galaxies, intergalactic medium, first generation of stars and galaxies, high redshift Universe, reionization, evolution of galaxies and stellar population, and number counts. Also covers luminosity functions, correlation functions, and clustering. Introduces new techniques and latest data sets and archives used for research. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 205 Classical Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing in Physics. Tensors, covariant derivative, the Riemann curvature tensor and Einstein's equation. The Schwartzchild metric and applications to the solar system and black holes. Gravity waves and expanding universe.

PHYS 208 General Relativity 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 205; graduate standing; or consent of instructor. An introduction to general relativity. Covers tensors, covariant derivatives, the Riemann curvature tensor, and Einstein's equation. Explores the Schwartzchild and Kerr black hole metrics and wormholes. Also addresses gravitational waves and their detection. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 209A Quantum Electronics 4 Lecture, 4.5 hours. Prerequisite(s): PHYS 135B, PHYS 156A; or consent of instructor. Quantum theory of light and interaction of light with atoms. Density matrix formulation of atomic susceptibility. Propagation of light in matter and optical waveguides. Optical resonators. Theory and operation of common lasers. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 209B Nonlinear Optics 4 Lecture, 4.5 hours. Prerequisite(s): PHYS 209A or consent of instructor. Wave propagation in nonlinear media. Electro-optic effect, three- and four-wave mixing, high-resolution nonlinear spectroscopies, rare atom and molecule detection, laser manipulation of particles, high-intensity laser physics, laser-plasma interactions. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 209C Advanced Topics in Quantum Optics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 209A, PHYS 209B; or consent of instructor. Advanced topics in quantum optics and nonlinear optics. Topics include high resolution spectroscopy, atom trapping and manipulation, transient and time-resolved spectroscopy, coherent spectroscopy, GHz to X-ray sources and spectroscopy and coherent control in atoms, molecules, liquids, solids, surfaces and interfaces. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable as topics change to a maximum of 12 units.

PHYS 210A Electromagnetic Theory 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Covers topics in electrostatics, including Coulomb potential, boundary value problems, multipoles, and dielectric media. Also addresses Laplace's equation and Green's function in Cartesian, spherical, and cylindrical coordinates.

PHYS 210B Electromagnetic Theory 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 210A; graduate standing; consent of instructor. Covers topics in electromagnetism. Includes magnetostatics, quasistationary electromagnetism, Maxwell's equations, gauge transformations, Maxwell's stress tensor, analyticity of dielectric susceptibility, and electromagnetic waves in uniform media and waveguides.

PHYS 210C Electromagnetic Theory 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 210B or consent of instructor. Covers electromagnetic radiation and scattering; propagation of electromagnetic fields in non-uniform media (geometrical optics, interference, and diffraction); special theory of relativity; Lagrangian formalism; and dynamics of relativistic particles in external fields. Also examines Cherenkov radiation and magnetic monopoles.

PHYS 211A Radiative Processes in Astrophysics 4 Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 135A, PHYS 135B, PHYS 136, PHYS 156A, PHYS 156B. Radiative transfer of continuum and line radiation, Einstein coefficients, photoionization equilibria, radiation by free electrons, bremsstrahlung and synchrotron emission, Compton and inverse Compton scattering, wave propagation through magnetized plasmas, atomic and molecular structure and spectra, atomic fine structure, and molecular hyperfine lines. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 211B Astrophysical Fluid Dynamics 4 Lecture, 3; consultation, 1 hour. Prerequisite(s): PHYS 211A. Covers hydrodynamics, sound waves, turbulence, supersonic turbulence, magnetohydrodynamics, Alfven waves, extragalactic relativistic jets, supersonic jets, galactic spiral structure and density-wave theory, accretion disk theory, Balbus-Hawley instability, and stellar winds. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 212A Thermodynamics and Statistical Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Covers thermodynamics, statistical mechanics, ideal Bose systems, ideal Fermi systems, and bulk motion. Cross-listed with MSE 204.

PHYS 212B Thermodynamics and Statistical Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MSE 204/PHYS 212A; graduate standing; consent of instructor. Addresses functional integrals and approximation techniques. Provides an introduction to phase transitions and the renormalization group.

PHYS 213 Astrophysics of the Interstellar Medium 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. An overview of the interstellar medium and relevant physical processes. Covers the structure and evolution of ionized hydrogen regions associated with massive stars and supernovae. Also addresses the neutral and ionized phases of the interstellar medium, as well as cooling processes. Includes the interpretation of spectral lines. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 214 Techniques of Observational Astrophysics 4 Lecture, 2 hours; laboratory, 3 hours; written work, 3 hours. Prerequisite(s): graduate standing. An introduction to the basic tools of observational astronomy. Topics include astronomical telescopes and detectors, observing techniques, calibration, and error analysis. Students whose research is related to astronomy receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 215 Dynamics and Evolution of Galaxies 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Discusses the structure, stability, and dynamic and cosmologic evolution of galaxies. Interprets observational data on galaxies within a coherent theoretical framework. Topics include potential theory, orbits, collisionless systems, and the structure and evolutionary history of galaxies. Students whose research is related to astronomy receive a letter grade other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 216 Star Formation 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Discusses the processes involved in the formation of stars: the initial conditions in the interstellar medium that leads to star formation and the formation of planets and planetary systems around young stars. Topics include molecular cloud formation, the properties of young stars, jets and outflows, massive stars, and cosmological star formation. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 217 Stellar Structure and Evolution 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Topics include physics of stellar structure and main sequence evolution, and energy production and transport; post main sequence evolution through the giant stage and the formation of compact objects; supernovae, nucleosynthesis, pulsars, and the roll of accretion within the framework of stellar evolution; and the physics of white dwarfs, neutron stars, and black holes. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 218 Fundamentals of Astrophysics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Develops basic astrophysical concepts from fundamental physics. Topics include nucleosynthesis, stellar structure, evolution of stars of different masses, end-states of stars, and bremsstrahlung and synchrotron radiation. Also covers cross-sections, opacities, hydrogen atom transitions, forbidden lines, and molecular lines. Addresses the ongoing search of life in the Universe. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 219 Cosmology and Structure Formation 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or the consent of instructor. Explores cosmology, models for the universe, galaxy formation scenarios, evolution of galaxies and stellar population, and number counts. Also covers star formation activity in the universe, cosmic background radiation, dark matter, and dark energy. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 220 Quantum Computing 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 201/MSE 207 or equivalent; graduate standing or consent of instructor. An introduction to quantum computing. Topics include qubits, entanglement, quantum gates, quantum circuit diagrams, simple quantum algorithms, quantum teleportation, quantum cryptography, Shor's factorization algorithm, Grover's search algorithm, and quantum error correction. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with EE 214.

PHYS 221A Quantum Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Examines the fundamental concepts of quantum mechanics including wave functions and the uncertainty relations. Also covers time dependence of quantum systems, such as the simple harmonic oscillator and simple two-level systems.

PHYS 221B Quantum Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 221A; graduate standing; consent of instructor. Covers angular momentum and approximation methods, including perturbation theory.

PHYS 221C Quantum Mechanics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 221B; graduate standing; consent of instructor. Covers symmetries in quantum mechanics, identical particles, and scattering theory.

PHYS 224 Frontiers of Physics and Astrophysics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. Covers particle physics to cosmology from an experimental perspective. Includes the present status of our understanding of the physics of the universe, the major challenges, and future opportunities. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 225A Elementary Particles 4 Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 221A, PHYS 221B, PHYS 221C; or consent of instructor. Provides an overview of particle physics. Topics include Quantum Electrodynamics (QED), the Quark-Parton Model, and Quantum Chromodynamics (QCD). Also discusses experimental techniques for particle detection and energy measurement. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 225B Elementary Particles 4 Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 225A or consent of instructor. Covers advanced topics in particle physics such as the Standard model, Charge-Parity (CP) violation and conservation laws, and mixing in the neutral strange and bottom meson systems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 226 Cosmology 4 Lecture, 3 hours; discussion, 1 hour., Prerequisite(s): graduate standing; PHYS 208. Discusses advanced topics in cosmology: Friedmann models and the large-scale structure of the universe, Hubble constant and deceleration parameter, and galaxy counting and the physics of the early universe. Also covers vacuum phase transitions, inflation, baryon number generation, fluctuations, topological defects and textures, primordial nucleosynthesis, density fluctuations, dark matter candidates, and the age of the universe. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 227 Particle Astrophysics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 226. An introduction to current research in particle astrophysics: the very early universe, the origin of matter, primordial perturbations, the origin of structure, the nature of dark matter, vacuum energy, matter-antimatter asymmetry, neutrino astrophysics, gravitational radiation, black holes, the origin of ultrahigh energy cosmic rays, and Hawking radiation. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 229 Theory of Dark Matter Halos and Galaxies 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. A theory-based study of the properties of dark matter halos and their connection to galaxy properties. Topics include dark matter collapse in the non-linear regime, Press-Schechter, self-similar collapse, acquisition of mass, and angular momentum. Includes the impact of dark matter properties on hosted galaxies, mergers, environmental effects, and scaling relations. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 230A Advanced Quantum Mechanics and Quantum Theory of Fields 4 Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 221A, PHYS 221B, PHYS 221C; or consent of instructor. Topics include quantization of fields for particles with spins 0, 1/2, and 1; path integrals; Feynman diagrams; and scattering amplitude and cross sections. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 230B Advanced Quantum Mechanics and Quantum Theory of Fields 4 Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 230A or consent of instructor. Explores renormalization of quantum field theory, gauge invariance, spontaneous breaking of gauge symmetry, Quantum Chromodynamics, and electroweak interactions. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 230C Advanced Quantum Mechanics and Quantum Theory of Fields 4 Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 230B or consent of instructor. A study of current topics in quantum field theory, including solitons and instantons, supersymmetry, and the unification of all forces. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 231 Methods of Theoretical Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. A study of analytic functions, Cauchy's theorem, Taylor series, Laurent series expansions, the residue theorem, and analytic continuation.

PHYS 234 Physics of Nanoscale Systems 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. Introduction to fundamental quantum physics in nanoscale systems and low dimensional materials. Including synthesis of low-dimensional material systems; physics-based experimental approaches to nanotechnology; mesoscopic quantum transport of electrons; quantum phenomena involving spin; silicon nanoelectronics and beyond; and future electronics based on topological materials. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with MSE 234A.

PHYS 235 Spintronics and Nanoscale Magnetism 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Provides an overview of contemporary issues in nanoscale magnetism and spin-dependent phenomena in solids, including the fundamentals of magnetism, magnetism in reduced dimensions, novel magnetic materials, spin-polarized transport, spin coherence in semiconductors, magnetization dynamics, and device applications. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with MSE 234B.

PHYS 236 Experimental Techniques in Condensed Matter Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. Survey of common experimental techniques used in the field of condensed matter physics. Topics include nanofabrication and characterization, advanced thin film growth methods, vacuum techniques, electrical and magnetic characterization, cryogenic instrumentation, optical measurements, X-ray techniques, data acquisition and analysis, and general lab techniques. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 237 Experimental Quantum Computing 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. Covers experimental approaches to quantum computing. Includes the basics of quantum computing and an introduction to physical realizations of a quantum computer. Focuses on ion traps and experimental implementation of quantum gates and quantum algorithms including search algorithms, quantum Fourier transform, and factorization. Also addresses quantum error correction codes. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 240A Condensed Matter Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 221C; graduate standing; or consent of instructor. Topics include classical and quantum theories of the electron gas; crystal and reciprocal lattices; crystal symmetries; electrons in a periodic potential; nearly free electrons; tight binding; band structure; metals, insulators and semiconductors; semiclassical dynamics; and semiclassical transport. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with MSE 214.

PHYS 240B Condensed Matter Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 240A; graduate standing; or consent of instructor. Topics include electron scattering, electron-electron interactions, classical and quantum harmonic crystals, and phonon dispersion relations. Also addresses dielectric properties, magnetism, and superconductivity. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 241A Advanced Statistical Physics and Field Theory 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 212B; PHYS 221C; graduate standing; or consent of instructor. Topics include elementary excitations in many-body systems, critical phenomena and the renormalization group technique, Green's functions and Feynman diagrams, and other field-theory techniques, and advanced topics in condensed matter physics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 241B Advanced Statistical Physics and Field Theory 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 241A. Topics include advanced field-theory techniques applied to many-body systems, exactly soluble classical and quantum models in one and two dimensions, quantum Hall effect, and other advanced topics in condensed matter physics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 241C Advanced Statistical Physics and Field Theory 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 241B. Topics include quantum magnetism, unconventional superconductivity, localization, transport phenomena, mesoscopic systems, nonequilibrium phenomena, and advanced field-theory methods, such as methods for treating disorder. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 242 Physics at Surfaces and Interfaces 4 Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Overview of surface science, electronic and geometric structure of clean surfaces, techniques for investigating structure, electron spectroscopy of surfaces, adsorption on surfaces, vibrations on surfaces, and epitaxial growth and applications of surface science. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 243 Foundations of Applied Machine Learning 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. For PHYS 243 online section; enrollment in the Online Master-in-Science in Engineering program. Covers basic principles of machine learning (ML) and introduces deep learning. Topics include ML algorithms, practical examples, and case studies for application of ML and deep learning to different disciplines. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 244 Application of Visualization in Data Science 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. For PHYS 244 online section; enrollment in the Online Master-in-Science in Engineering program. Develops interactive visualization and data mining techniques for massive multidimensional datasets. This includes 3D visualization and interaction, fast data exploration and development of big data solutions for text and binary data-intensive applications. Includes details of advanced data visualization techniques and the tools for handling and visualizing massive datasets.

PHYS 245 Atomic and Solid-State Physics With Positrons 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or the consent of instructor. An overview of the field of antimatter science. Includes beta decay, positron sources, positronium physics, positron annihilation spectroscopy, slow positron physics, solid state physics with slow positrons, atomic physics with slow positrons, and many positron physics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 246 Biological Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate or consent of instructor. Introduces topics at the interface of physics and biology: cell physiology, probability and information, diffusion, random walks, electrostatics, elasticity of biopolymers and membranes, DNA topology, friction in fluids, and low Reynolds numbers. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 247 Introduction to Applied Data Science 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 247 online section: enrollment in the Online-Master-in-Science in Engineering program. PHYS 247 in-person section: graduate standing; or consent of instructor. Designed to provide all the necessary background knowledge to follow other data science courses. Covers basic principles of machine learning (ML) and Python Programming and introduces deep learning. Topics include ML algorithms, practical examples, and case studies for application of ML and deep learning to different disciplines. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 250 Special Topics Seminar in Physics and Astronomy 2 Seminar, 2 hours. Prerequisite(s): graduate standing in Physics and Astronomy or consent of instructor. Includes oral presentations and intensive small-group discussion of selected topics in the area of specialization of each faculty member. Emphasizes recent advances in the special topic area; course content varies accordingly. Students who present a seminar receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable.

PHYS 256 Advances in Nanoscale Physics 1 or 2 Seminar, 1 hour; individual study, 0 or 3 hours. Prerequisite(s): graduate standing. Seminars on current topics in nanoscale physics and materials science, including nanoelectronic devices, nanoelectromechanical systems, nanoscale biophysics, spintronics, nanoscale magnetism, nanophotonic systems, and advanced characterization techniques. Students who give class presentations receive credit for 2 units; other students receive credit for 1 unit. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 258 Seminar in Surface Science 1 Seminar, 1 hour. Prerequisite(s): graduate standing in Physics or Chemistry or consent of instructor. Oral presentations by participating visiting scholars, postdoctoral researchers, students, and UCR faculty on current research topics in surface science. Students who present a seminar or submit a term paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Cross-listed with CHEM 258.

PHYS 260 Special Topics in Condensed Matter Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. Explores topics in condensed matter physics that emphasize recent advances. Content varies. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable to a maximum of 12 units.

PHYS 261 Special Topics in Astrophysics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. Explores topics in astrophysics that emphasize recent advances. Content varies. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable to a maximum of 12 units.

PHYS 262 Special Topics in High Energy Physics 4 Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; or consent of instructor. Explores topics in high energy physics that emphasize recent advances. Content varies. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable to a maximum of 12 units.

PHYS 288 Current Research Themes in Physics 2 Seminar, 1 hour; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Introduces first-year graduate students to current issues in physics research at UCR. Involves seminars by faculty on their research and interaction with advanced students and postdoctoral researchers. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 289 Colloquium in Physics 1 Colloquium, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Specialized discussions by visiting scientists, faculty, and students on current research topics in physics. Graded Satisfactory (S) or No Credit (NC). course is repeatable.

PHYS 290 Directed Studies 1 to 6 Research, 3 to 18 hours. Prerequisite(s): graduate standing; consent of instructor; consent of advisor or Department Chair. Individual study, directed by a faculty member, of specially selected topics. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 291 Individual Study in Coordinated Areas 1 to 6 Individual Study, 3 to 18 hours. Prerequisite(s): graduate standing; consent of instructor. Faculty-assisted programs of individual study for candidates who are preparing for examinations. Graded Satisfactory (S) or No Credit (NC). Course is repeatable within the following limits: Up to 6 units may be taken prior to award of the Master's degree, such units to be in addition to minimum unit requirements for the degree. Up to 12 additional units may be taken (continued) prior to advancement to candidacy for the Ph.D.

PHYS 296 Summer Research in Physics 2 Research, 20 hours per quarter. Prerequisite(s): graduate standing; or consent of instructor. Provides mentoring by faculty on research and interaction with advanced graduate students and postdoctoral researchers. Graded Satisfactory (S) or No Credit (NC).

PHYS 297 Directed Research 1 to 6 Research, 3 to 18 hours. Prerequisite(s): graduate standing; consent of instructor. Original research, in an area selected for the advanced degree, performed under the direction of a faculty member. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 299 Research For Thesis Or Dissertation 1 to 12 Thesis, 3 to 36 hours. Prerequisite(s): graduate standing; consent of instructor. Original research, in an area selected for the advanced degree, performed under the direction of a faculty member. This research is to be included as a part of the dissertation. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

Professional Courses

PHYS 301 Teaching of Physics at the College Level 2 Lecture, 2 hours. Prerequisite(s): graduate standing in Physics or consent of instructor. Required of all Teaching Assistants in the Department. Designed to introduce effective methods for teaching physics and to evaluate and improve teaching skills. Topics covered include lecture techniques, effective visual aids, improving laboratory and recitation section learning situations. Credit not applicable toward degree course requirements. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 302 Teaching Practicum 1 to 4 Consultation, 1 hour; laboratory, 3 to 12 hours; practicum, 3 to 12 hours. Prerequisite(s): Appointment as a departmental Teaching Assistant; graduate standing. Supervised teaching in Physics courses and regular consultation with faculty supervisor(s) regarding teaching responsibilities. Credit not applicable toward degree course requirements. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 12 units.

PHYS 401 Professional Development in Physics and Astronomy 2 Lecture, 1 hour; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor; Introduces students to strategies for successful graduate study and early career development. Covers research and professional ethics, scientific writing (proposals, manuscripts, and abstracts), conference presentations, effective job search skills including preparation of curriculum vitae and networking, effective oral presentations, and job interviews. Visiting experts may give lectures on various topics. Graded Satisfactory (S) or No Credit (NC)

Plant Biology

See Botany and Plant Sciences

Microbiology and Plant Pathology

Subject abbreviation: PLPA
College of Natural and Agricultural Sciences

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Kerry Mauck, Ph.D. (Entomology)
Philippe Rolshausen (BPSC)
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Undergraduate Curriculum

The Department of Microbiology and Plant Pathology participates in the Microbiology and Botany and Plant Sciences majors leading to the baccalaureate degree. See the Microbiology or Botany and Plant Sciences section of this catalog.

Graduate Program

The Department of Microbiology and Plant Pathology offers the M.S. and Ph.D. degrees in Plant Pathology.